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INVESTIGATION OF MICROSTRUCTURAL AND METALLURGICAL PROPERTIES OF CORTEN A588 GRADE STEEL GTAW JOINTS

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ABSTRACT

Corten A588 steel is a high strength low alloy structural steel having 0.19% wt of carbon content. It has good corrosion resistance when exposed to extreme atmospheric conditions. Corten steel weighs less than other grades of carbon steel without compromising its strength. Corten A588 is mainly used in building railway wagons. In rail coach manufacturing arc welding process GTAW is carried to make permanent joints using ER70S-6 filler rod. Lack of fusion, lack of penetration, and lack of porosity are the major problem in welding corten A588 grade steel. In this research work, micro structural and metallurgical properties on Corten A588 Grade Steel of GTAW joints is evaluated.

KEYWORDS: Corten A588 Grade Steel, FESEM & EDAX, GTAW, Hardness & Microstructure

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Original Article

INTRODUCTION

Weathering steel is atmospheric corrosion resistant steel having a unique function of rust curing rust. When corten steel is exposed without painting to atmosphere, it starts rusting same like ordinary steel. But fine textured tight protective rust formed due to the alloying elements suppresses the corrosion rate. This unique property makes corten steel to be used for various applications without paint. The service life of corten steel is increased when painted than that of ordinary steel applied with coating.

Corten steel is paintable same like ordinary steel. The progress in the rusty area formed due to painting defects in painted corten steel will be suppressed. Corten steel has been used in various applications like bridges, railway coaches, buildings etc. Rust stabilization treatments on corten steel reduce the life cycle cost and environmental problems in many applications. The cheering reddish brown color of the protective rust gives an aesthetic advantage. The extraordinary appeal makes corten steel to be used in sculptures, architectural and outdoor construction application.

Corten steels can be welded, cold and hot formed and gas cutting same as that of ordinary steel. The alloying elements of corten steel like copper (Cu), Chromate (Cr) is added to improve weathering resistance. The carbon content is kept very low to provide good quality weld. Corten steel can be welded using Metal active gas (MAG), Gas metal arc (GMAW), Gas tungsten arc (GTAW), submerged arc welding.

Corten A588 steel or weathering steel is being widely used in the areas such as construction of bridges, walls, roofs, towers and also in several architectural applications. Corten A588 Grade steel is a high strength low alloy steel (HSLA) which constitutes copper, chromium, nickel, phosphorous and silicon. The Phosphorous and Silicon that are present in Corten A588 Grade steel are responsible for enhancing the corrosion resistant properties. After the

prolonged exposure to the atmosphere the compact adherent protective rust layer (patina) is formed over the steel surface which in turn effectively protects the corrosion.

Kihira's et al., (1990) research reveals that the protective patina layer is a dual layer where crystalline FeOOH is formed on the top surface and amorphous iron hydroxide is formed beneath the surface. Desmond observes the nano-phase goethite particles (FeOOH) which is lesser than 15 nm and magnetic goethite particle (FeOOH(m)) greater than 15 nm on corten A588 steel surface. This is formed due to the substitution of chromium, adhered to inner oxide layer and adjacent to the substrate to form a diaspore structure.

However, the black color formation during welding process and prolonged interaction of water (water pockets) with corten A588 steel surface restricts its wide range of applications. In addition, the phase changes in the corten A588 steel surface during the welding process influences the corrosion and erosion process which reduces the mechanical properties. For a longer run i.e. for 4 to 8 years Corten A588 grade steel starts to corrode thereby becoming fatigue due to adverse environmental factors

LITERATURE REVIEW

R. Ravichandran (2013) in his research work identified that the internal residual stress induced and galvanic / bimetallic corrosion are the major problems in the railway industry. Choosing of filler material for welding of mild steel to Corten steel and stainless steel to corten steel is another major issue. In his research he has addressed some of the problems faced during welding like carbide precipitation / sensitization (weld decay) / intergranular corrosion, hot cracking (solidification cracking), heat tints, dis-colorization. Balamurugan. S et.al (2015) in their research article found that a microstructure of corten steel had a combination of ferrite and carbide inclusion. The micro hardness of the coarse grained HAZ (CGHAZ- just adjacent to the weld metal region) is 148 HVN and that of Fine grained HAZ (FGHAZ- very close to the base metal region) is 162 HVN. The base material (corten steel) has a hardness of 142 HVN.

Byju John, Sathiya Paulraj, Jolly Mathew (2016) in their research work found that the cooling rate of shielding gas having high percentage of Argon 90% and above had better results. Welding of corten steel using Argo shield (80% Ar – 20% CO2) had better depth of weld penetration and uniform weld bead. The microstructure like acicular ferrite has formed which improves the corrosion resistance, strength and toughness of the weld. Jianping Niu et.al (2015) in their research work summarized that the applications of corten steel that has been extended to rail industry, shipping containers, construction etc. weathering steel is manufactured by two methods. The first process is the hot cast billet is hot rolling process and the second process is continuous casting and rolling process

R. Megavarnan et.al (2019) has summarized in the tensile strength along the grain direction was 508.11 Mpa and perpendicular to the grain flow is 449.47 Mpa. During Root and face bend test there were no signs of cracks at the weld zone. The micro hardness on the parent metal, heat affected zone and the weld zone was about 181, 186 and 190 HVN respectively. The microstructure of the parent metal is of uniform grain size of ferrite with lean pearlite. At the heat affected zone the microstructure reveals coarse grain structure of ferrite and lean pearlite. Dendrite microstructures were formed in the weld zone.

S. Ravikumar et.al (2017) has concluded in their research article that the ultimate tensile strength of 546.76 N/mm2 and maximum displacement of 10.27 mm. The maximum micro hardness of the weld zone is 211.8 HVN. The maximum hardness at the heat affected zone and the base metal is 201.5 and 153.9 HVN respectively. The micro structure of the parent metal is uniform grains of pearlite in ferrite matrix. Fine chromium carbides are also dispersed in the ferrite matrix.

Recrystallised grains of perlite in formed in the ferrite matrix having grain size varying from 25-30 microns. Finer dendrite patters are formed in the weld zone due to rapid cooling from liquidous to solids state.

CORTEN A588 GRADE STEEL

Weathering steel is also known as Corten steel which is a high strength low alloy steel (HSLA) which contains low percentage carbon in it [2]. It forms rust on the layer which is called a patina [7]. It varies with ordinary steel by the addition of copper, chromium and nickel alloying elements. Corten steel has a high resistance to corrosion. Corrosion of Corten steel mainly depends on oxygen and moisture. Patina acts as the protective barrier layer that reduces corrosion and further damage caused by access of oxygen, moisture and contaminants. It is mostly used in railway wagons, transmission towers etc [1]. It weighs less than other grades of low carbon steel without a reduction in strength. The average Vickers hardness of Corten A588 Grade steel is 174 HVN for a load of 100gms. The base material is cut in 1 x 1 x 0.2 cm by using a shear cutting process. The chemical composition of Corten A588 Grade Steel as shown in table.1

Table 1: Chemical Composition of Corten A588 Grade Steel

Elements	Composition (%)
C	0.12
SI	0.298
Mn	0.391
P	0.087
S	0.013
Cr	0.546
Ni	0.218
Cu	0.302

FILLER MATERIAL: (ER70S-6)

ER-An electrode is a mild steel solid wire which is used for making higher strength and proper weld joints.70- A gives a minimum of 70000 pounds of tensile strength per square inch of weld. S-solid wire has a good amount of deoxidizing agent, cleaning agent and copper coating on the electrode [7]. In order to weld corten A588 Grade steel CO_2 and Ar gas mixture is used as shielding gas [5],[1],[6]. Lack of porosity, Corrosion on the heat affected zone and lack of fusion are the common problems that arise during welding of corten A588 Grade steel plate. The chemical composition of filler material as shown below in table 2

Table 2: Chemical Composition of Filler Material (ER70S-6)

Elements	Composition (%)
C	0.1
Si	0.8
Mo	0.12
S	0.03
Cr	0.15
Ni	0.13
Cu	0.5

EXPERIMENTAL WORK

Gas Tungsten Arc Welding (GTAW) is a type of arc welding process in which the electrode is non-consumable. To make a permanent weld joint by GTAW process ER70S-6 is used as filler wire. The weld fusion zone is protected from the

oxidation by using Carbon dioxide and argon as shielding gas during GTAW welding process. Corten A588 Grade steel plate is cut into 300 x 150 x 2 mm by using shear cutting process. Table 3 below shows the welding parameters used for preparing corten A588 Grade steel GTAW joints.

Table 3: Welding Parameters

Types of Welding	GTAW
Current(A)	174
Voltage(V)	18
Filler wire	ER70S-6
Filler rod diameter(mm)	3
Shielding gas	Argon
Gas flow rate(m^3/sec)	80/2
Root gap(mm)	2
Time taken (sec)	64
Weld length(mm)	150
Weld speed(mm/sec)	2.34

RESULTS AND DISCUSSIONS

Hardness Tests

Vickers hardness testing machine model: VM-50 is used to find the micro hardness of the welded joint at base material, heat affected zone and weld zone. A load of 1kg is applied for time duration of 20 seconds to take hardness survey on the weld joint. The transformation of structure occurs from Austinite to ferrite and from ferrite to pearlite with some martensite formation which is caused during excessive hating on the weld zone and heat affected zone (HAZ). The hardness on the heat affected zone and the base is relatively lower than the welded zone because of the excessive heat absorbed during the welding process [1], [3]. The average Vickers hardness obtained at the weld zone is 247.75 HVN which is higher than of the heat affected zone which is 225.25 HVN and for the base material is 175.6 HVN. During the welding process loss of some alloying elements such as chromium (Cr), Manganese (Mn) and Nickel (Ni) occurs due to melting and evaporation. The Vickers hardness survey of Corten A588 Grade steel GTAW joint is shown in table 4 and Figure 1 shows the hardness survey graph of the Corten A588 Grade steel GTAW joint.

Table 4: Vickers's Hardness Test of GTAW Joint

Location	Distance	Hardness HVN (1kg)
Weld Metals Towards Left Side	1	183
	2	194
	3	226
	4	235
	5	251
	6	257
Weld Centre	7	243
Weld Metals Towards Right Side	8	240
	9	236
	10	204
	11	172
	12	164
	13	165

Figure 1: Vickers Hardness Graph of CortenA588 Grade Steel GTAW Joint.

Microstructure

The microstructure of base, HAZ and weld zone of Corten A588 Grade steel GTAW Joints is observed using optical metallurgical microscope at a magnification of 200 X as shown in Figure 2. Grains are elongated along rolling direction on the base material. The grain sizes of the ferrite in the base metal is 25 to 30 microns as shown in figure 2(a).

After GTAW welding process of Corten A588 Grade steel is completed the weld is allowed to rapidly cooled. This produces fine grains of pearlite with precipitated pearlite. The grain size of the ferrite grains present in HAZ ranges from 15 to 20 microns as shown in figure 2(a). The grains in the left side of the heat affected zone shows uniform fine grains with 15 to 20 micros and at the weld zone shows dendritic grains with varying pools of ferrite whose grain sizes ranges from 30 to 40 microns as shown in from figure 2(b). There is no distinct interface layer between weld zone and HAZ. Bifurcation of these zones could not be resolved from figure 2(c). Rapidly solidified filler metal at the weld zone produces a dendritic pattern of grains with varying pools of ferrite whose sizes vary from 30 to 40 microns depending on the proximity to the heat affected zone as shown in figure 2(c). The large dendrite grains of size between 40 to 50 microns are formed at the core weld regions as shown in figure 2(d). These large size dendrides are formed due to the slow cooling rate at the core weld region.

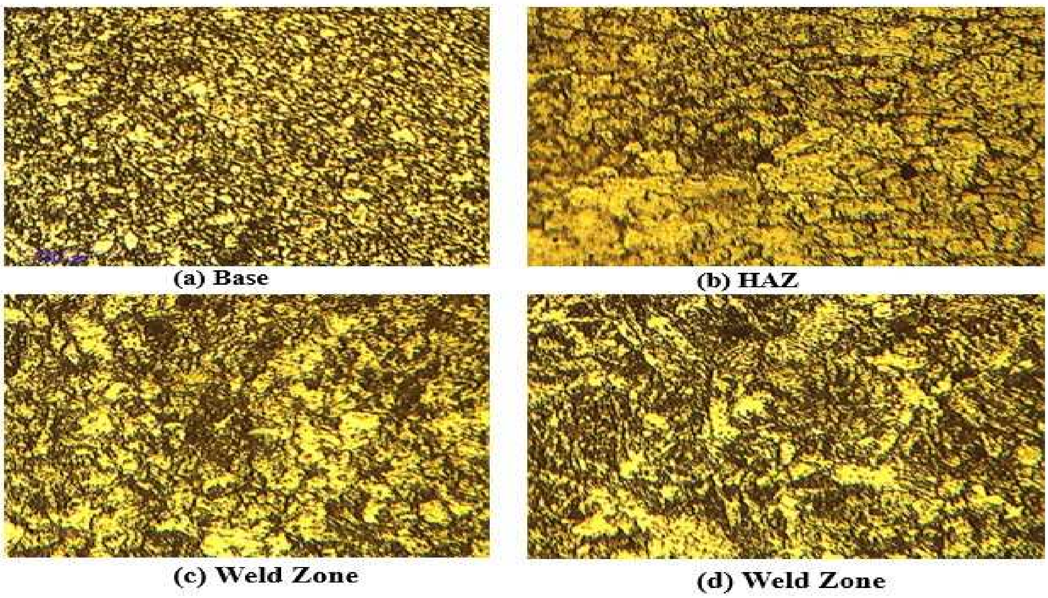

Figure 2: Microstructure of Corten A588 Grade Steel GTAW.

FESEM and EDAX

EDAX analysis gives all the elements present in GTAW welded Corten A588 Grade steel rendering to the weight and atomic ratios. The concentration of Fe on the grain matrix of the base material Corten A588 Grade steel is 97.62% when compared to other elements like Cr, Si which was present like traces which is about 1.49 and 0.89% respectively as shown in figure 3a. But EDAX elemental mapping on the grain boundaries on the base material shows only 58.22% of Fe and 36.84% of C was present where as elements like Cr, Mn and Ni was present like traces which is 2.33, 1.58 and 0.03% respectively as shown in figure 3b.

EDAX elemental mapping on the grain boundaries on the weld zone shows only 81.85% of Fe and 16.08% of C were present where as elements like Si, Mn was present with traces ranging from 1.22, 0.86 % respectively as shown in figure 3c. But the concentration of Fe on the grain matrix at the weld zone is 97.82 % when compared to other elements like Si and Cr which was present like traces which is 1.19 and 0.99 % respectively as shown in figure 3d, when welded elements like chromium (Cr), Nickel (Ni) disappears due to melting and evaporation.

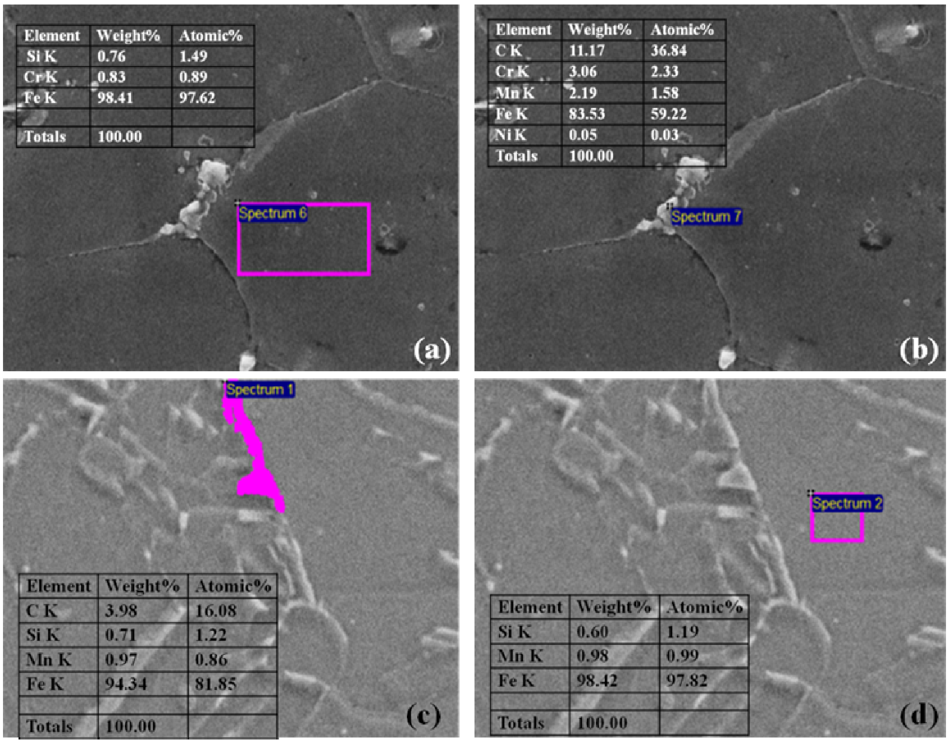

Figure 3: FESEM and EDAX of Corten A588 Grade Steel GTAW Joint (a&b) Base Material (EDAX on the Grain & Grain Boundary) (c&d) Weld Zone (EDAX on the Grain & Grain Boundary).

CONCLUSIONS

The average Vickers hardness of GTAW Corten A588 Grade steel at the weld zone is 247.75 HVN which is much higher than of the HAZ which is 225.25 HVN and for the base material is 175.6 HVN.

The microstructure of Corten A588 Grade steel on the weld zone has large dentric structure of size 40 to 50 microns and fusion at the filler metal at the weld zone also produces a dendritic pattern of grains size 30 to 40 microns with varying pools of ferrite. There is no distinct layer between weld zone, HAZ and base material hence bifurcation of these

zones is not clear. The grain size of the ferrite grains present in HAZ is 15 to 20 microns. The grains at the base material are elongated along the rolling direction and having grain size of 25 to 30 microns.

The welded elements like chromium (Cr), Nickel (Ni) disappears due to melting and evaporation. Hence the Fe on the grain matrix at the weld zone is 97.82 % when compared to other elements like Si and Cr which was present like traces which is 1.19 and 0.99 % respectively where as Fe on the grain matrix of the base material Corten A588 Grade steel is 97.62% when compared to other elements like Cr, Si which was present like traces which is 1.49 and 0.89% respectively.

REFERENCES

1. *Byju John, Sathiya Paulraj, Jolly Mathew, the role of shielding gas on mechanical, metallurgical and corrosion properties of corten steel welded joints of railway coaches using gmaw, Advances in Science and Technology Research Journal, Volume 10, No. 32, Dec.(2016).*
2. *Panneerselvam, K., & Lenin, K. (2013). Study on hardness and micro structural characterization of the friction stir welded Nylon 6 plate. Int J Mech Eng, 2, 51, 62.*
3. *P. Dhaiveegan, N. Elangovan, T. Nishimura and N. Rajendran, Weathering Steel in Industrial-Marine-Urban Environment: Field Study, Materials Transactions, January 18, (2016).*
4. *Ehsan Gharibshahiyan, Abbas Honarbakhsh Raouf, Nader Parvin, Mehdi Rahimian, The effect of microstructure on hardness and toughness of low carbon welded steel using inert gas welding, Materials and Design 32 (2011).*
5. *Mahmud Sarkari Khorrami, Mohammad Ali, Mostafaei, Hesam Pouraliakbar, Amir Hossein Kokabi, Study on microstructure and mechanical characteristics of low-carbon steel and ferritic stainless steel joints, Materials Science & Engineering A,15 April (2014).*
6. *Jasim, T. A., Haleem, A. H., & Hadi, Z. A. An Investigation of The Influence Of Nano-Cobalt Oxide on Microstructure and Mechanical Properties of 7075 Aluminium Alloy.*
7. *Her-Yueh Huang, Effects of shielding gas composition and activating flux on GTAW weldments, Materials and Design 30 (2009).*
8. *Behcet Gulenc, Kaya Develi, Nizamettin Kahraman, Ahmet Durgutlu, Experimental study of the effect of hydrogen in argon as a shielding gas in MIG welding of austenitic stainless steel, International Journal of Hydrogen Energy 30 (2005).*
9. *J. R. Deepak, V. K. Bupesh Raja, Mittapalli Janardhan Guptha, Palaparthi HariDurga Prasad, V. Sriram, Experimental Investigation of Mechanical Properties of Welded Corten Steel A588 Grade Plate Using ER70S - 6 Filler Material for Construction Application, Materials Science and Engineering 197 (2017).*
10. *R. B. Durairaj, Madhu Chereyala, G. Mageshwaran & Jeya Jeevahan (2016): Surface roughness and corrosion characterisation of multi-walled carbon-nano tube-reinforced zirconium composite coated over SS316L, International Journal of Ambient Energy, DOI: 10.1080/01430750.2016.1237891.*
11. *Sudheesh, P. K., & Govindan, P. (2013). Experimental investigations and optimization of jig grinding process. International Journal of Research in Engineering & Technology, 1(3), 65–76.*
12. *V. Sriram, G. Mageshwaran , R B Durairaj, P. Sureshkumar, J. Sathish, “Design And Analysis Of Composite Transmission Shaft”, Journal of Chemical and Pharmaceutical Sciences ISSN: 0974-2115 Volume 9 2016, Issue 3Page:2510–2514.*
13. *R B Durairaj, Madhu Cheryala, Mageshwaran, Britto Joesph, “Corrosion behavior of Multi walled carbon nano tubes reinforced Zirconium oxy chloride Composite coated over SS316 L in sodium chloride solution”, Journal of Chemical and Pharmaceutical Sciences ISSN: 0974–2115 Volume 9 2016, Issue 3Page:2876–2878.*

14. *R B Durairaj, G Mageshwaran, V Sriram, Investigation on Mechanical Properties of Glass and Carbon Fiber Reinforced With Polyester Resin Composite, International Journal of Chem Tech Research Vol.9, No.06 pp 424–431, 2016.*

15. *Veeresh, C., Varma, S. V. K., & Praveena, D. (2015). Heat and mass transfer in MHD free convection chemically reactive and radiative flow in a moving inclined porous plate with temperature dependent heat source and joule heating. International Journal of Management, Information Technology and Engineering, 3(11), 63–74.*

16. *Balamurugan. S, vasiga, d. and gokulanathan, l. (2015) Stainless steel of AISI 304 to corten steel joint using MAG welding process, international journal of current research vol 7, issue, 12, pp.24693-24700, december, 2015*

17. *S. Ravikumar, j. Vishal, k. Vigram and a. N. Ganesh babu (2017) Material characteristic study of cold rolled graded thin sheet by using TIG welding process for rail coaches, ARPN journal of engineering and applied sciences, vol. 12, no. 19, October 2017*

18. *R. Megavarnan, G. Rajamurugan, R. Shanmuga Prakash (2017) Comparative Study on Mechanical Properties of GMA Welded IRSM41 Mild Steel Plate Based on Grain Flow Direction Applied Mechanics and Materials, ISSN: 1662-7482, Vol. 854, pp 38-44*

19. *Jianping Niu, Yujian Li, Lixin Zhao, Yu Han, Weimin Gao (2015) The Research Situation and Development Trend of Weathering-Steel, Applied Mechanics and Materials Vols. 713-715 (2015) pp 2962-2965.*

20. *R. Ravichandran (2013) Stainless Steel Welding in Railways, Advanced Materials Research Vol. 794 (2013) pp 340-350*

21. *Byju John, Sathiya Paulraj, Jolly Mathew (2016) The Role Of Shielding Gas On Mechanical, Metallurgical And Corrosion Properties Of Corten Steel Welded Joints Of Railway Coaches Using GMAW, Advances in Science and Technology Research Journal, Volume 10, No. 32, Dec. 2016, pages 156–168*